Science Activity 3.5 What Is The Magnetic Field Of An Electromagnet?

Objective: To discover what the magnetic field of an electromagnet is

Materials:
- Lantern battery, 6 volts
- A compass
- Insulated bell wire, 3 m long
- Several large nails

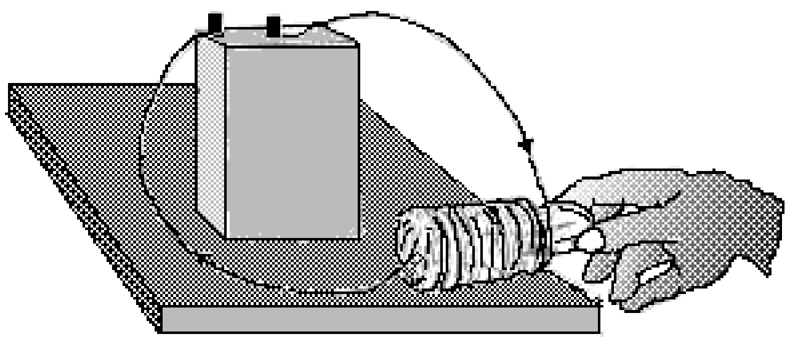


Figure B

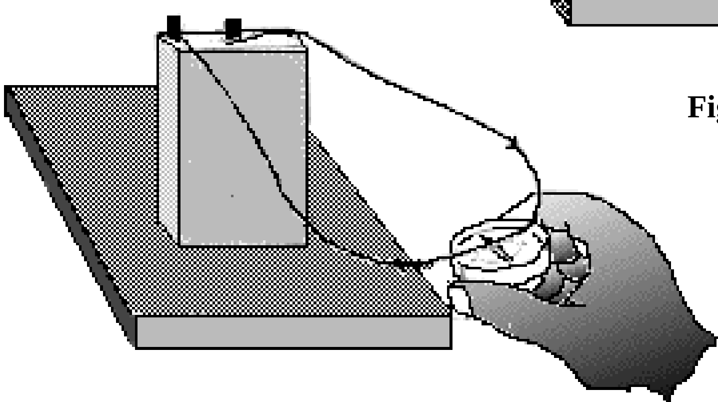


Figure A

Procedures:
1. Connect one end of the wire to the battery. Arrange the wire so it runs vertically past the edge of the table. See **Figure A** above.
2. Move the compass near the wire and then around the wire. Note the direction of the needle.
3. Connect the other end of the wire to the battery. Again move the compass around the wire and note the direction of the needle. Immediately disconnect one end of the wire from the battery. CAUTION: If wire becomes very hot, disconnect it and wait for it to cool before continuing.

4. Wind the disconnected wire into15 to 20 turns of coil about 5 cm in diameter. The compass should be able to pass through the coil. See **Figure B** on page 53.
5. Move the compass around and through the coil. Record the position of the needle.
6. Connect the ends of the wire to the dry cell. Again move the compass around and through the coil. Disconnect the wire from the battery. Record your observations of the compass needle.
7. Reverse the connections of the wire to the battery terminals. Repeat Step 6.
8. Hold the compass near one end of the coil. Insert the nails into the coil. Describe the effect on the compass. Disconnect the wire from the battery.

Assessment and Review:

Observations:
Record your observations

Step 2:____

Step 3:____

Step 5:____

Step 6:____

Step 7:____

Step 8:____

Assessment and Review:
1. Does a wire carrying an electric current generate a magnetic field? Give a reason for your answer.
2. What is the direction of the magnetic field around a straight wire?
3. What is the direction of the magnetic field in the coil?
4. How does reversing the direction of current flow through the coil affect the magnetic field?
5. What effect does putting iron nails into the core have on the magnetic field?

Science Activity 3.6 Making A Current Detector

Objective: To create an instrument called a galvanoscope which can detect an electric current.

Materials:
• Compass
• 7.5cm x 10cm in block of wood
• 10 meters of insulated copper wire (#20 to #26 gauge)
• A small piece of cardboard
• Thumbtacks
• Current source (1.5-volt dry cell or a 6-volt lantern battery)

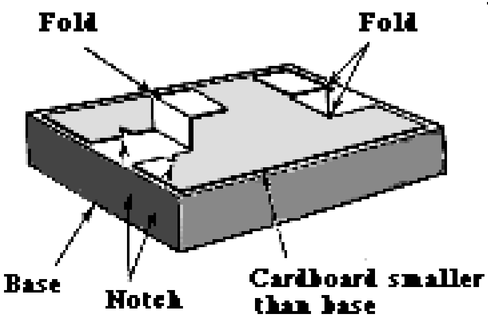


Figure A

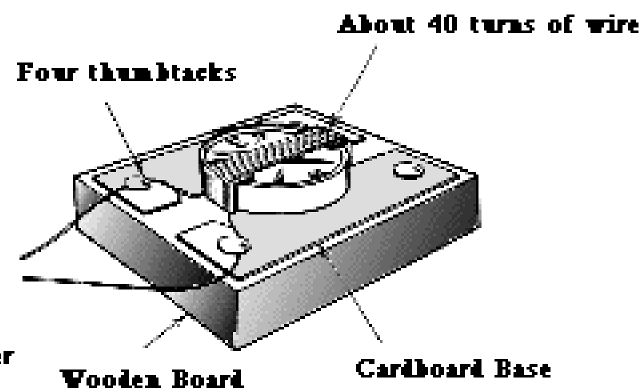


Figure B

Teacher Preparation:
Electric current is invisible and can be detected only by the effect it produces. This activity will show you how to construct a sensitive detector (a galvanoscope) which can determine if a current is flowing, or if a source is capable of producing a current. In the previous experiments, it was demonstrated that when a current is flowing through a wire, the compass needle is deflected. A galvanoscope indicates the presence of an electric current. This current detector is similar in principle to many electric meters. It demonstrates that the more current that flows through a coil of wire, the greater the magnetic field and the greater the deflection of the compass needle.

Procedures:

1. Cut out a cardboard base big enough to hold your compass as shown in **Figure A** on page 55.
2. Wind about 40 turns of insulated wire closely over the base and compass, leaving about 30 centimeters of wire before starting the first turn and after the last.
3. Wrap the two ends of wire once around each leg of the cardboard base and into the little notch, so the wires are held securely.
4. Fasten the whole assembly to the wooden block with the four thumbtacks loosely on the side of the board where the wire comes out, and wrap a few turns of each wire around them.
5. Attach about 25 centimeters of wire to each tack, and scrape off the enamel from each wire end for about 2cm.
6. The 40 turns of wire increase the sensitivity of the galvanoscope by 80, over a single wire across the compass. Place the galvanoscope in such a way that when there is no current flowing, the coil is directly over and under the compass needle as it points North and South. See **Figure B** on page 55.
7. Test the galvanoscope by connecting one of the wires to the terminal of a dry cell, and touch the other wire to the other terminal. Watch what happens to the compass needle. The swing ing compass needle proves that an electric current is flowing through the coil.
8. Now reverse the connections, and observe that the compass needle will deflect in the oppo site direction. The amount of deflection tells whether the current is strong or weak. The greater the compass deflection, the higher the current.

Assessment and Review:

1. Test your galvanoscope with 60 turns of wire. Does the current seem stronger or weaker than the 40 turns of wire?

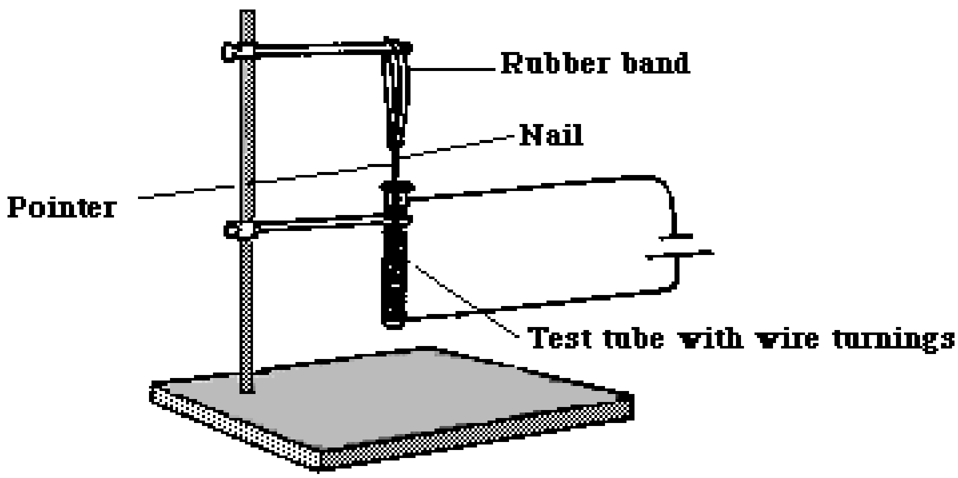
2. Test the galvanoscope with 20 turns of wire. What do you observe about the strength of the current?

3. Describe the relationship between the strength of an electric current and the length of coiled wire.

Science Activity 3.7 Making A Simple Meter

Objective: To make and test a simple meter

Materials:
• Iron nail
• Bell wire
• Ring stand and clamp
• Switch
• Meter stick
• Masking tape
• Glass tubing or small test tube
• A paper clip
• Long, thin rubber band
• Ammeter
• Variable DC source



Procedures:
1. Wind 100 to 150 turns of bell wire around the tube. Hold the wire in place with masking tape.
2. Connect the ends of the wire to a variable DC source and a switch.
3. Clamp the coil to the ring stand. Attach the nail to the rubber band and suspend it from the ring stand so that the nail is just inside the top of the coil. (See diagram.)
4. Make a pointer out of a paper clip and attach it to the top of the nail. Mount a piece of paper behind the pointer so you can record the position of the top of the nail.
5. Mark the position of the nail when the ammeter reads zero current.
6. Vary the voltage source so the current increases to 1 Amp.
7. Repeat Step 6, adjusting the voltage so the current increases 1 Amp. each time.

8. Measure the deflections of the nail from the zero position. Record the currents and respective deflections in the data table.

Assessment and Review:
1. Make a graph of the current versus deflection.
2. What kind of relationship does the graph show?
3. What are the units of the slope?
4. Could you adapt your meter to use in quantitative experiments?
5. What are some limitations of your meter?

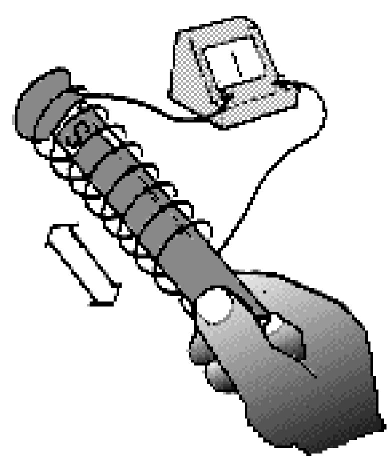
Data Table		
Trial	Current (Amp)	Deflections (Cm)
1		
2		
3		
4		
5		
6		

Science Activity 3.8 Measuring The Strength Of An Electric Current

Objective: To determine the strength and direction of an electric current

Materials:
• Galvanometer
• Insulated bell wire (three meters)
• Strong bar magnet

Teacher Preparation:
In the Science Activity 3.6 we created a galvanoscope, an instrument used to detect the presence of an electric current. In this activity, we will use a galvanometer, an instrument which measures the strength of an electric current.



Procedures:
1. Wind the wire into a 20 turn coil, 5 cm in diameter. Connect the wire to the galvanometer. Record **galvanometer readings** in the data table after each of the steps below (Steps 2-9).
2. Move the bar magnet, North pole first, into the coil and record what you see.
3. Hold the magnet motionless in the coil and record the reading.
4. Pull the magnet out of the coil, North pole first and record the reading.
5. Move the magnet into the same end of the coil, but this time South pole first and record the reading.
6. Move the magnet into the opposite end of the coil, South first and record the reading.
7. Move the magnet slowly back and forth in the coil and record the reading.

8. Move the magnet back and forth in the coil, but much faster than in step 7, then record the reading.
9. Change the number of turns in the coil. Repeat steps 7 and 8.Record what you see.

Observations:

Step	Needle Displacement Strength	Direction
2		
3		
4		
5		
6		
7		
8		
9		
10		

Assessment and Review:
1. How does the galvanometer indicate the direction and strength of current flowing in the coil?
2. How does the direction of the current depend on whether the magnet is moving in or out of the coil?
3. How does the direction of the current depend on the direction of the magnetic field?
4. How does the direction of the current depend on the end of the coil into which the magnet moves?
5. How does the current depend on the speed of the movement of the magnet?
6. How does the current depend on the number of turns in the coil?
7. What kind of current is generated when the magnet does not move in the coil?
8. How can you generate current with a coil and a magnet?

INVESTIGATING ELECTROMAGNETIC FIELDS

Science Activity 3.9 Magnetic Field Around A Current-Carrying Conductor

Objective: To demonstrate the magnetic field around a current-carrying conductor

Materials:
• Wire hanger (or stiff wire 60 centimeters long)
• Compass
• Two feet of insulated copper wire
• Battery
• 20 x 20 centimeters cardboard

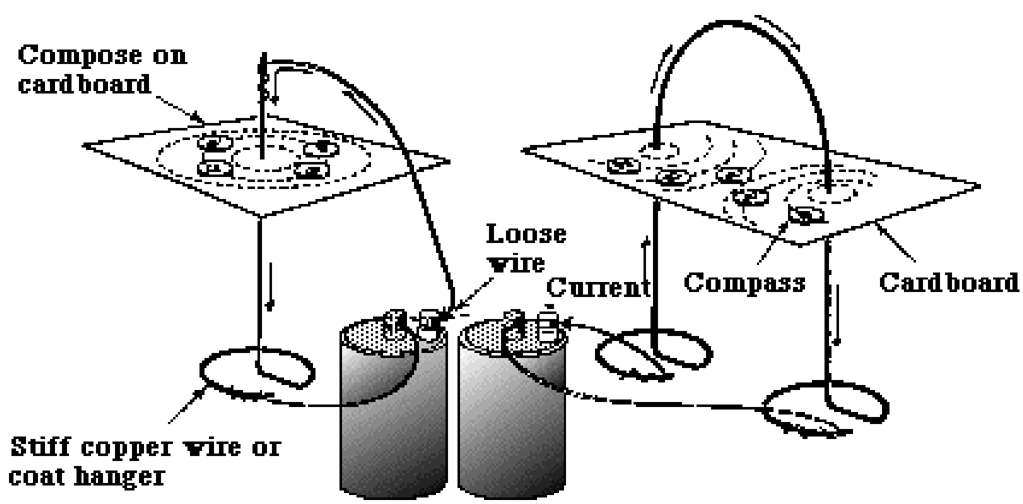


Figure A

Procedures:
1. Make a stand as illustrated in **Figure A** from a wire hanger or a stiff piece of wire.
2. Scrape the coating off very thoroughly for about 2 centimets at either end of the hanger.
3. Take a piece of cardboard at least 20 centimeters square with a hole in the middle and draw three concentric circles on it. These should be spaced 2.5 centimeters apart with the inner circle about 5 centimeters from the wire, which serves as center. We are going to use these circles as reference points for the compass to show the direction of the magnetic field.
4. Center the board on the stand so it stays about half way up without slipping down. This can be accomplished either by pushing the wire hanger through the cardboard so it will be held by friction or by making a little collar on the wire out of cellulose tape right underneath the cardboard.

5. Connect the stand with a wire to one terminal of the battery as shown. Lay the compass on any spot on the first circle, and tap the loose wire to the other battery terminal so that a current will flow. If the circuit has been connected properly, the needle will align itself in a direction tangent to the circle on which it lies. It will point in the direction of the circumference of thecircle at that point.
6. Move the compass to another position on the circle. Again tap the loose wire to the free terminal, and note the direction in which the compass is pointing. Move it to a third, fourth, and fifth position all around the circle, and you will see that at all times the compass will be pointing in the same direction as the circumference.
7. Move on to the next circle, and repeat the experiment. You will see that in all positions the compass needle will align itself in the same direction. In other words, the compass will point in a circular position around the wire on any of the three circles. This indicates that the direction of the magnetic field is a constant one, that it is located all around the wire, and that it spreads out from its center in a pattern similar to that which forms when a pebble is thrown into a lake.
8. To show that this magnetic field is not located only at this particular spot on the wire, move the cardboard up or down about 2.5 or 5 centimeters. You will see that when the current flows, the compass needle will align itself in the same direction and with the same degree of response at various distances from the wire as it had before.

Assessments and Review:

1. What is the position of the compass at any point along the circle (a circular position around the wire)?
2. What conclusions can you draw about the direction of the magnetic field?
3. What happens to the magnetic field as you get farther away from the wire?

Science Activity 3.10 Showing The Magnetic Field In Another Way

Objective: To demonstrate the evidence of a magnetic field using iron filings

Materials:
- Wire stand from the last experiment
- Iron filings
- Battery
- Insulated copper wire
- 20 X20 centimeters cardboard

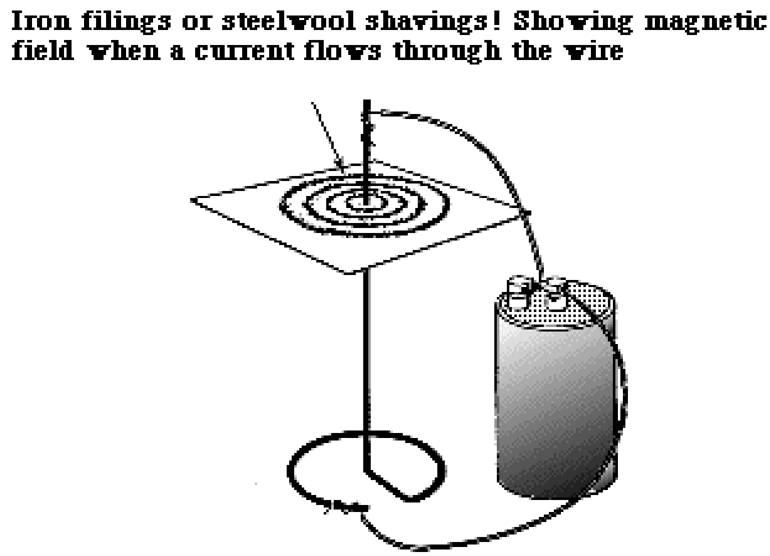


Figure 1

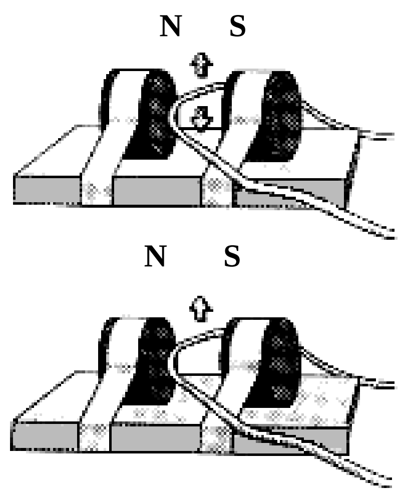
Procedures:
1. Using the wire stand and cardboard, sprinkle iron filings all around the center of the card board. See **Figure 1** above.
2. Connect the loose lead of the insulated copper wire to the free battery terminal, and tap the cardboard slightly to permit the filings to move around a little.
3. Record what happens to the filings after you tap the cardboard.
4. Remove the loose lead from the battery terminal. Tap the cardboard and record what happens to the iron filings.
5. Connect the loose lead to the battery terminal again and repeat step three.

Assessment and Review:
1. What happens to the iron filings when you tap the cardboard while the loose lead is con nected to the battery terminal?
2. What type of pattern is formed by the filings when the terminal is connected? What does this indicate about the magnetic field?
3. What type of pattern is formed by the filings when the cardboard is tapped and the terminals are disconnected?

Science Activity 3.11 The Motor Effect

Objective: To show how a magnet exerts a force on a current-carrying wire

Materials:
• Four to six small disk magnets
• One or two 1.5 volt flashlight batteries
• Approximately 5 centimeters of flexible wire (magnet wire)
• Masking tape
• One wooden block (about 5 x 10 x 15 centimeters)
• A knife or sandpaper



Teacher Preparation:

The simple device constructed here shows that when an electrical current flows through a magnetic field, a force is exerted on the current. This force can be used to make an electric motor.

Procedures:
1. Group the disk magnets into a single cylindrical pile.
2. Place the pile on the board so that it can be rolled along the board.
3. Split the pile in the middle, leaving a gap of about 1.5 centimeters between the faces of the two groups.
4. Tape the two groups to the board. A north pole will face a south pole across the gap.
5. Tape the battery onto the board at a convenient place.

6. Remove the insulation from the ends of the wire. (Use a knife for stranded wire, or sandpaper to remove the nearly invisible insulating enamel from magnet wire.)
7. Loop the wire through the gap between the magnets, with the ends of the wire close enough to the battery to touch it.

Assessment and Review:

Touch one end of the wire to the positive side of the battery and simultaneously touch the other end of the wire to the negative side. The wire loop will jump either up or down.

If you reverse the direction of current flow, the wire will jump in the opposite direction. To reverse the current, attach the lead that was connected to the positive end of the battery to the negative end, and vice-versa.

What's going on?

The magnetic field of the disk magnets exerts a force on the electric current flowing in the wire. The wire will move up or down, depending on the direction of the current and the direction of the disks' magnetic field.

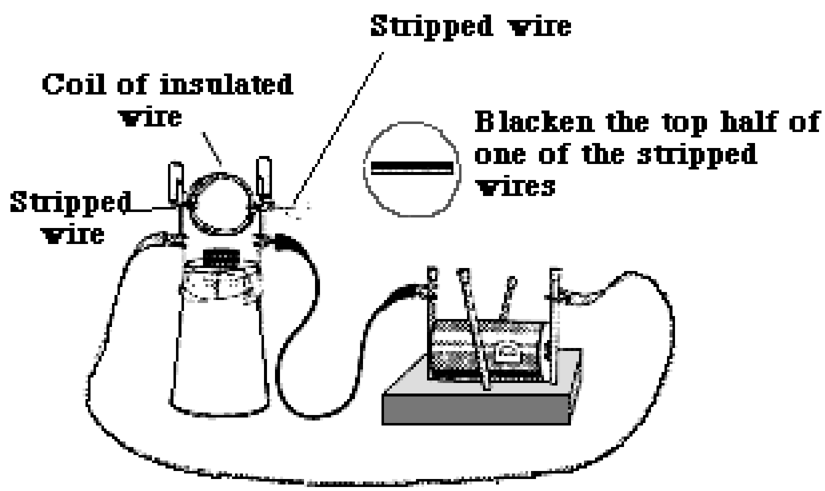
To predict the direction of movement, you can use a mathematical tool called the right-hand rule. Put your right hand near the section of wire that goes between the magnets. Make your hand flat, with your thumb sticking out to the side. (Your thumb should be at a right angle to your fingers.) Place your hand so that your thumb points along the wire in the direction that the electric current is flowing (current flows from the positive terminal of the battery to the negative terminal), and so that your fingers point from the north pole of the disk magnets toward their south pole. Your palm will then naturally "push" in the direction of the magnetic force on the wire.

The deflecting force that a magnet exerts on a current-carrying wire is the mechanism behind the operation of most electric motors. Curiously, the reverse effect is also true: move a loop of wire across the pole of a magnet and a current will begin to flow in the wire. This, of course, is the principle of the electric generator. The electric current you generate by moving this single loop of wire through the weak magnetic field of the disk magnets is too weak to detect with all but the most sensitive of microammeters.

Science Activity 3.12 Stripped Down Motor

Objective: To construct an electric motor

Materials:
• Five small disk or rectangular ceramic magnets
• Two large paper clips
• Plastic, paper, or styrofoam cup
• Solid (not stranded) enameled or insulated 20 gauge copper wire
• Masking tape
• Battery or power supply



Teacher Preparation:

A coil of wire becomes an electromagnet when current passes through it. The electromagnet interacts with a permanent magnet, causing the coil to spin. You have just created an electric motor!

Current flows through the wire coil and creates an electromagnet. One face of the coil becomes a north pole, the other a south pole. The permanent magnet attracts its opposite pole on the coil and repels its like pole, causing the coil to spin.

Another way to describe this operation is to say that the permanent magnets exert forces on the electrical currents flowing through the loop of wire. When the loop of wire is in a vertical plane, the forces on the top and bottom wires of the loop will be in opposite directions. These opposite directed forces produce a twisting force, or torque, on the loop of wire that will make it turn.

It is important to paint half of the wire black because if both of the permanent magnets are mounted with their north poles facing upward, the north pole of the permanent magnet would repel the north pole of the loop-electromagnet and attract the south pole. But once the south pole of the loop-electromagnet was next to the north pole of the permanent magnet, it would stay there. Any push on the loop would merely set it rocking about this equilibrium position. The painting prevented current from flowing for half of each spin. The magnetic field of the loop-electromagnet is turned off for that half spin. As the south pole of the loop-electromagnet comes closest to the permanent magnet, the paint turns off the electric current. The inertia of the rotating coil carries it through half of a turn, past the insulating paint. When the electric current starts to flow again, the twisting force is in the same direction as it was before and the coil continues to rotate in the same direction.

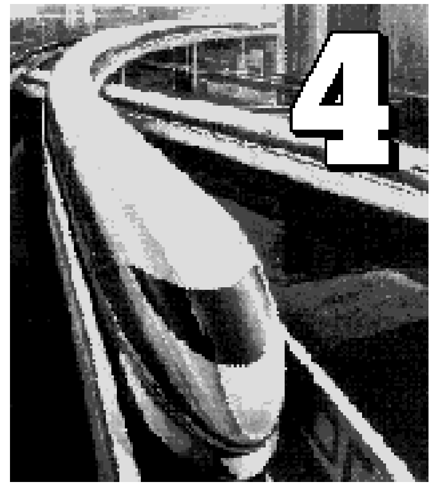
Procedures:

1. Wind the copper wire into a coil about 2.5 in diameter. Make four or five loops.Wrap the ends of the wire around the coil a couple of times on opposite sides to hold the coil together. Allow 5 centimeters projecting from each side of the coil, and cut off any excess.
2. Make sure the ends of the wire are bare (remove insulation or enamel if present). Color one side of one of the projecting ends black with the felt-tipped pen. (Note: it is very important that the orientation of the painted side corresponds to the orientation shown in the drawing. If the coil is held vertically, paint the top half of one of the wires black).
3. Turn the cup upside-down and place two magnets on top in the center.
   Attach three more magnets inside the cup, directly beneath the original two magnets. This will create a stronger magnetic field as well as hold the top magnets in place.
4. Unfold one end of each paper clip and tape them to opposite sides of the cup, with their unfolded ends down. (See diagram on page 66.)
6. Rest the ends of the coil in the cradles formed by the paper clips. Adjust the height of the paper clips so that when the coil spins, it clears the magnets by about 1/2 centimeters. Adjust the coil and the clips until the coil stays balanced and centered while spinning freely on the clips. Good balance is important in getting the motor to operate well.
5. Once you have determined how long the projecting ends of the coil must be to rest in the paper-clip cradles, you may trim off any excess wire. (The length of the projecting ends depends on the separation of the paper-clip cradles, which in turn depends on the width of thebase of the cup you are using. See diagram.)
6. If you are using a battery, place it in a battery holder (see diagram). Use the alligator clip leads to connect the battery or power supply to the paper clips, connecting one terminal of the battery to one paper clip and the other terminal to the other paper clip.

7. Give the coil a spin to start it turning. If it does not keep spinning on its own, check to make sure that the coil assembly is well balanced when spinning, that the wire is bare, that the projecting end has been painted with the black marker as noted, and that the coil and the magnet are close to each other but do not hit each other. You might also try adjusting the distance separating the cradles: this may affect the quality of the contact between the coil and the cradles.

Chapter 4

Magnetic Levitation and Propulsion



Repulsive & Attractive Levitation!

There are two ways to float a Maglev: repulsive levitation and attractive levitation. “Repulsive” Maglev is pushed upward by the forces between like ends of magnets. “Attractive” Maglev is pulled upward by the attractive force between magnets and steel. The pictures below show and explain how the two types of Maglev levitate. Note that Maglev uses “guideway” instead of “track”. That is because there is no track for Maglev like there is for a rolling train.

An example of “Repulsive” Maglev can be found in Japan. They have a test vehicle that uses superconducting magnets and levitates about 4 inches (100 mm) above the guideway. Japan is probably 10 years away from selling their system.

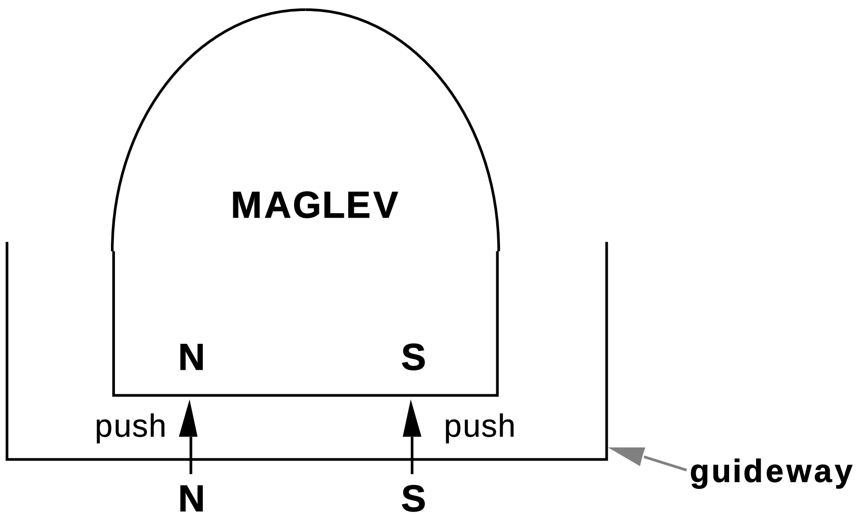
The Japanese rely on coils of superconducting wire to produce the vehicle’s magnetic field. These superconducting magnets produce a field of the same polarity as that induced in the coils located at the bottom of the guideway; the resulting magnetic repulsion keeps the vehicle aloft.

An example of “Attractive” Maglev can be found in Germany. The German Transrapid Maglev system floats 3/8 of an inch (10 mm — about the width of your baby finger!) above the guideway. (The State of Florida will buy Transrapid from Germany for a 15 mile route in Orlando. Look for it in the next 4 or 5 years!) The levitating force comes from an attractive pull between a laminated iron rail in the guideway and a conventional electromagnet in the vehicle.

"Repulsive" Maglev

(pushed upward)

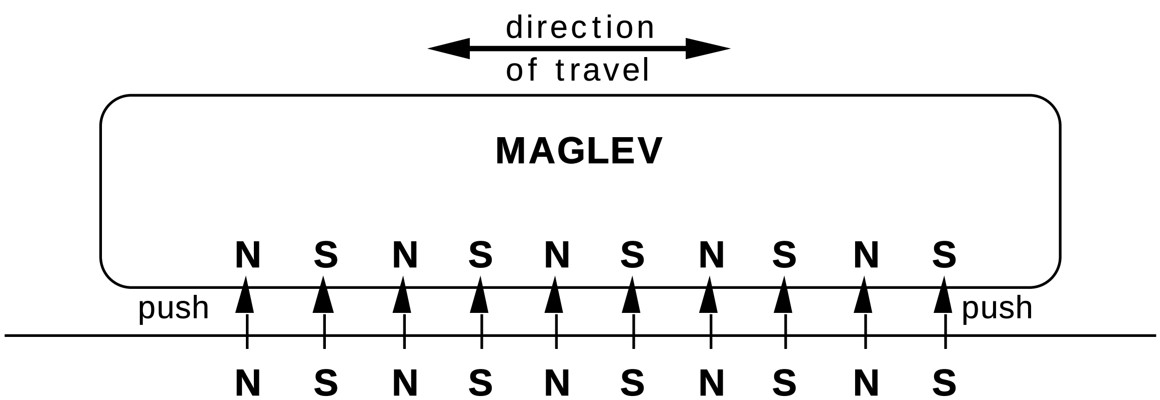
Rear View



Maglev is lifted by magnetic forces. The black arrows show the vehicle being pushed upward. Remember a north pole repells a north pole and a south pole repells a south pole. In this picture imagine the vehicle traveling away from you into the page!

"Repulsive" Maglev

Side View

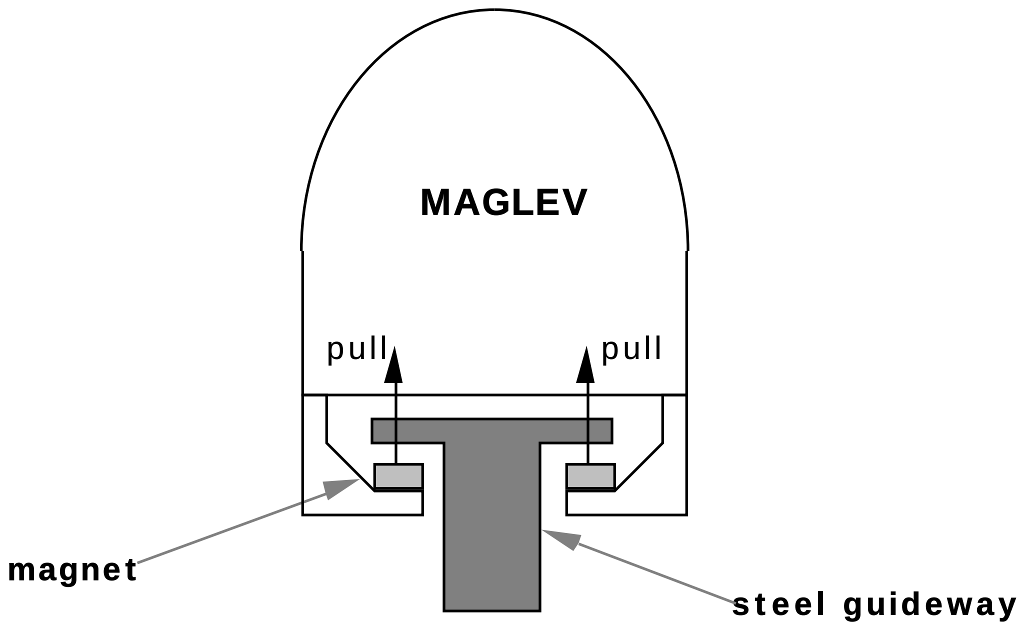


The vehicle is forced upward by a magnetic force. This keeps it from ever touching the ground. Maglev can float as much as 5 inches off the ground! Imagine a vehicle loaded with 150 passengers floating in the air!

"Attractive" Maglev

(pulled upward)

Rear View

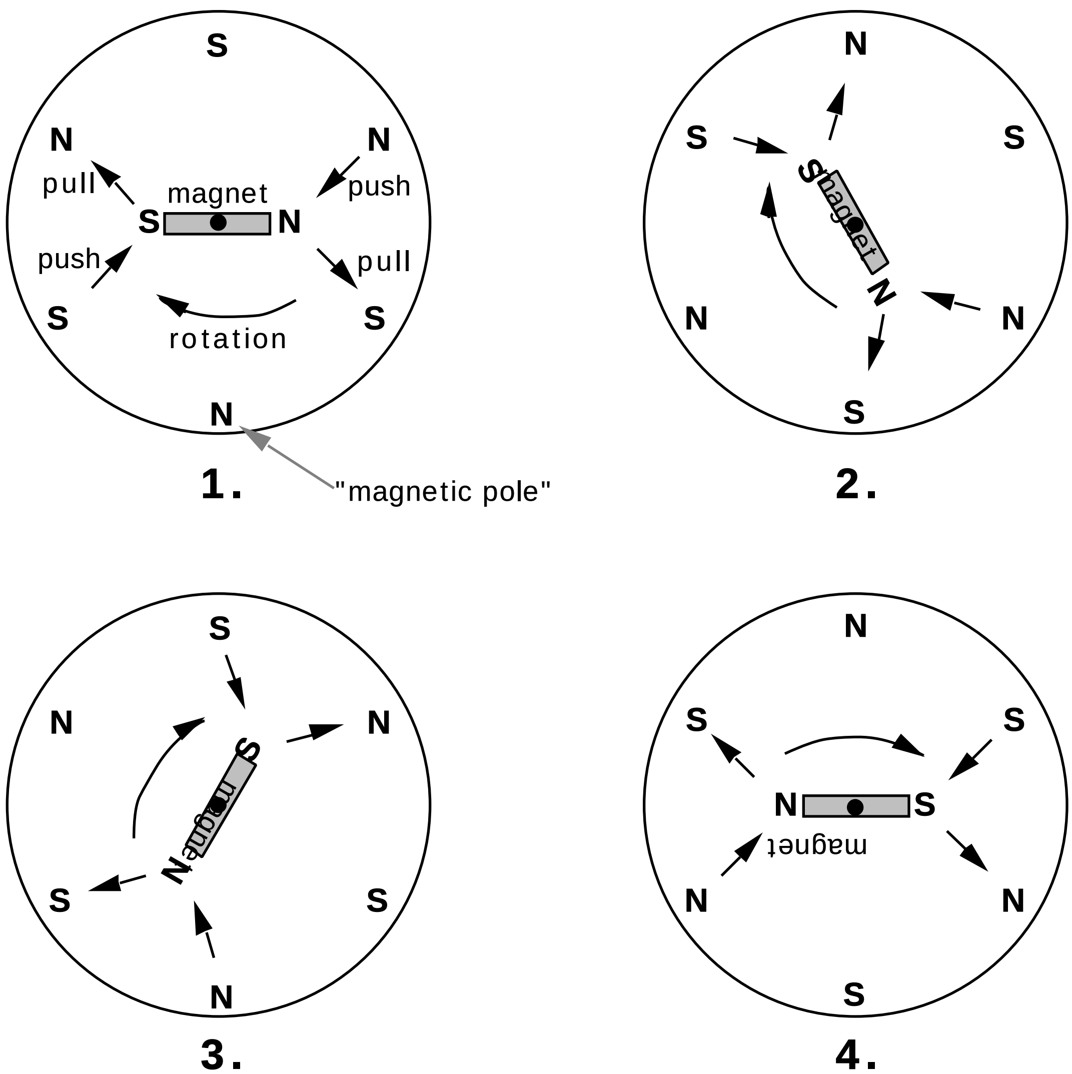


The black arrows show the magnets being pulled up to the steel. When the magnets move upward, the whole vehicle moves upward and lifts off the guideway! Remember both ends of a magnet are attracted to steel, that is why I didn't label N and S. Again, imagine that the vehicle is moving into the page!

Propulsion (Moving Maglev)

Maglev is pushed and pulled forward by a **linear electric motor**, also called a “straight-line” electric motor because the motion is in a straight line.

Circular Electric Motor

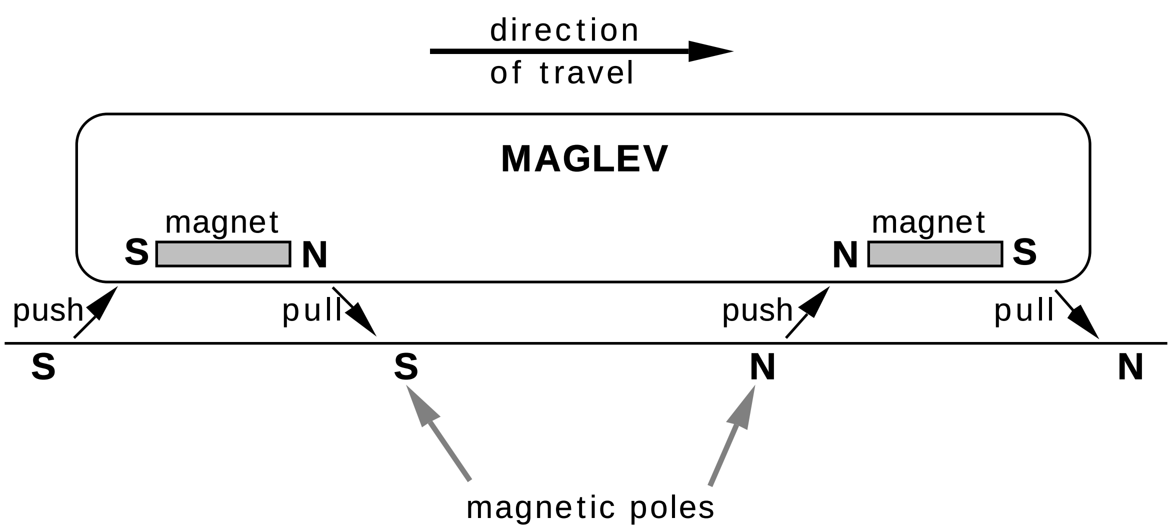


In all four positions the magnet is pushed from behind and pulled from in front. This causes the magnet to turn around in a circle. (That's why it's called a Circular Electric Motor). You can see that the magnet has rotated half way around the circle when it reaches position 4. Notice that the magnetic poles around the motor must change from S to N and back again to keep the magnet in the center rotating. This kind of motor can be found in your washing machine, dryer, electric mixer and even in electric cars!

Now, we are ready to look at a straight-line electric motor. This kind of motor also moves by magnetic forces. This is how Maglev moves!

How Maglev Moves:
Linear (Straight-Line) Electric Motor

Side View



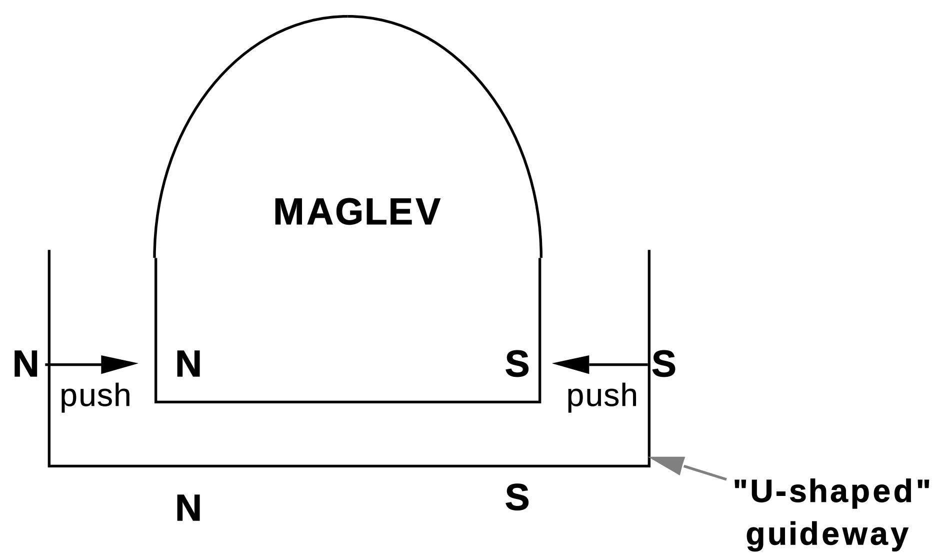
This works very much like the circular electric motor that we just saw. Here the magnets go in a straight line instead of around a circle. Each magnet is pushed forward from behind and pulled forward from the front causing the vehicle to move forward. Notice again that the magnetic poles on the guideway must change from S to N and back again to keep the vehicle moving foward. Maglev can go 300 miles per hour or faster!

Now that we know how Maglev floats and how Maglev moves, the next question is:
How do you keep Maglev from falling off the guideway?

Maglev is kept centered on the guideway by magnetic forces! The pictures below show Maglev being pushed or pulled from both sides preventing it from falling off either side. If a strong wind pushed the vehicle over to one side, these magnetic forces would push it back the other way and keep the vehicle centered. As an added safety feature, the vehicle can travel in a **"U-shaped"** guideway, or wrap around a **"T-shaped"** guideway. These specially-shaped guideways would stop Maglev from falling off the side in an emergency.

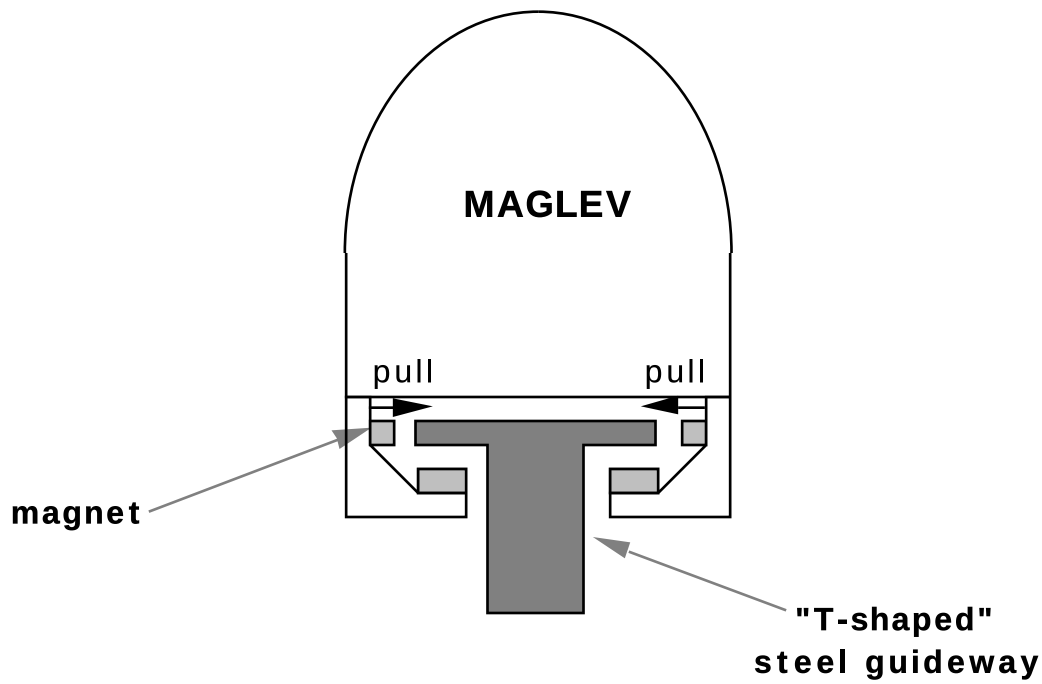
Centering Forces for "Repulsive" Maglev in "U-shaped" guideway

(keeping it from falling off the side!)



Centering Forces for "Attractive" Maglev in "T-shaped" guideway

(keeping it from falling off the side!)



WORKING WITH MAGNETIC CURRENT

Science Activity 4.1 Eddy Current Motor

Objective: To build an eddy current motor

Materials:
- Strong magnet
- Small aluminum pie plate
- Sewing needle
- Cork
- 60 centimeters of thin string or heavy thread

Teacher Preparation:

A piece of aluminum or copper will not be attracted by a magnet. Nevertheless, we will be able to show in this experiment that a magnet can indeed exert a force of some sort on these metals.

The speedometer of an automobile operates on this principle. As a car moves, a magnet is rotated at a speed depending on the speed of the car. The magnet in turn exerts a drag on a piece of metal attached to a pointer on a scale. This pointer indicates the speed at which the car is moving. A hair spring restricts the pointer movement and thus keeps it from revolving as our little motor does. But as we find out, the faster the magnet spins, the greater the drag. Therefore, the faster our car moves, the farther over the speedometer pointer will swing.

Procedures:
1. Push a sewing needle through a cork so that its point sticks up.
2. Balance an aluminum foil pan of the type used for a small frozen cake or pie on the needle point so that it is level and free to spin.
3. Tie a strong horseshoe magnet to a piece of string about 60 centimeters long. The exact length of the string is not too important.
4. Hold the string so that the magnet is free to spin very closely over the center of the aluminum pan. Note the illustration.
5. Now twist the string about 30 times, carefully holding the magnet so that it remains steady over the center of the pan, and then let the string go.
6. As the magnet spins, it will induce electric currents called eddy currents in the aluminum. The eddy currents in turn will produce a magnetic field on top of the aluminum. This field, affected by the field of the magnet, will make the pan turn in the direction in which the magnet is spinning. The faster the magnet spins, the greater will be the magnetic field which is built up in the pan, and the faster the pan will spin.

Assessment and Review:

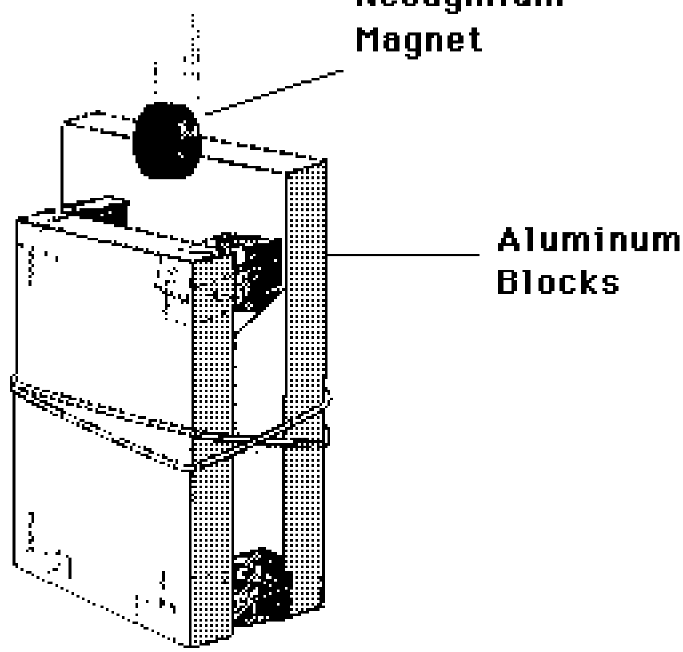
Fill in each blank with the appropriate word:

1. Attraction or repulsion of charges depends on their signs: positive or negative. Attraction or repulsion of magnets depends on their magnetic ________________:___________________ or __________________.
2. Opposite poles attract: like poles___________________.
3. A magnetic field is produced by the __________________ of electric charge.
4. Clusters of magnetically aligned atoms are magnetic __________________.
5. A magnetic ____________________ surrounds a current-carrying wire.
6. When a current-carrying wire is made to form a coil around a piece of iron, the result is an ___________________.
7. A charged particle moving in a magnetic field experiences a deflecting _________________ that is maximum when the charge moves __________ _____________ to the field.
8. A current-carrying wire in a magnetic field experiences a ___________ that is maximum when the wire and field are _____________________ to one another.
9. A simple instrument designed to detect electric current is the ______ __________________ when calibrated to measure current, it is an _____ __________________: when calibrated to measure voltage, it is a ___________________.
10. The largest magnet in the world is the ___________________ itself.

Science Activity 4.2 Eddy Currents

Objective: To demonstrate eddy currents

Materials:
• Cow magnet or neodymium magnet
• A non-magnetic object (pen or pencil)
• Three foot length of aluminum, copper, or brass tubing
• Three foot length of PVC tubing
• Optional- two thick flat pieces of aluminum with thick walls, large enought to enclose a magnet cardboard
• rubber bands or cord.



Teacher Preparation:

When a magnet is dropped down a metallic tube, the changing magnetic field created by the falling magnet pushes electrons in the metal tube around in circular, eddy-like currents. These eddy currents have their own magnetic field that opposes the fall of the magnet. The magnet falls dramatically slower than it does in ordinary free-fall in a non-metallic tube.

Procedures:
1. Hold the metal tube vertically. Drop the cow magnet through the tube.
2. Drop a non-magnetic object, such as a pen or pencil, through the tube.
3. Notice that the magnet takes noticeably more time to fall.
4. Now try dropping both magnetic and non-magnetic objects through the PVC tube.

Additional Activity:

Demonstrate dropping a neodymium magnet between two thick, flat pieces of aluminum. The aluminum pieces should be spaced just slightly farther apart than the thickness of the magnet. A permanent spacer can be made with cardboard and masking tape, if you don't want to hold the pieces apart each time. Rubber bands or cord can hold the pieces all together. The flat surfaces need to be only slightly wider than the width of the magnet itself. Thickness, however, is important. The effect will be seen even with thin pieces of aluminum, but a thickness of about 1 centimeter will produce a remarkably slow rate of fall. Allow at least a 15 centimeter fall.

Assessment and Review:

As the magnet falls, the magnetic field around it constantly changes position. As the magnet passes through a given portion of the tube, this portion of the tube experiences a changing magnetic field, which induces the flow of eddy currents in an electrical conductor, such as the copper or aluminum tubing. The eddy currents create a magnetic field that exerts a force on the falling magnet. This force opposes the magnet's fall. As a result of this magnetic repulsion, the magnet falls much more slowly.

Eddy currents are often generated in transformers, and lead to power losses. To combat this, thin laminated strips of metal are used in the construction of power transformers, rather than making the transformer out of one solid piece of metal. The thin strips are separated by insulating glue, which confines the eddy currents to the strips. This reduces the eddy currents, thus reducing the power loss.

With the new high-strength neodymium magnets, the effects of eddy currents become even more dramatic. Eddy currents are also used to dampen unwanted oscillations in many mechanical balances. Examine your balances to see whether they have a thin metal strip that moves between two magnets.

MAGNETIC FORCES AND THEIR EFFECTS

Science Activity 4.3. Strange Attractor

Objective: To observe unpredictable motion from the attraction and repulsion of magnets

Materials:
- Ring stand and clamp
- Four to six ceramic magnets
- Paint, masking tape or typewriter correction fluid
- Fishing line or string

Teacher Preparation:

Patterns of order can be found even in apparently disordered systems. A magnet swinging over a small number of fixed magnets can show chaotic motion. This type of pendulum can show entrancing and unpredictable motion which can be a further study in the science of chaos and turbulence.

Procedures:
1. Put all the magnets together in a pile so that they stick together magnetically. By doing this, you are orienting the magnets so that all of the north poles point in one direction and all of the south poles point in the other direction.
2. Mark the top of each magnet with paint, tape, or correction fluid, identifying all the matching poles.
3. Use string or fishing line to hang one magnet from the ring-stand so that it is a free-swinging pendulum. The magnet can hang in any orientation.
4. Arrange the other magnets on the ring stand base in an equilateral triangle measuring a couple of inches on a side. Position the magnets so that they all have same pole up.
5. Adjust the length of the pendulum so that the free-swinging magnet will come as close as possible to the magnets on the ring stand base without hitting them or the base itself.
6. Give the pendulum magnet a push, and watch!

Assessment and Review:

Vary the location and poles of the magnets to develop other patterns. You can arrange the magnets so that all of them have the same pole up, or you can mix them up. Notice that a tiny change in the location of one of the fixed magnets or in the starting position of the pendulum magnet may cause the pendulum to develop a whole new pattern of swinging.

What's going on? The force of gravity and the simple pushes and pulls of the magnets act together to influence the swinging pendulum in very complex ways. It can be very difficult to predict where the pendulum is going to go next, even though you know which magnets are attracting it and which are repelling it. This sort of unpredictable motion is often called *chaotic motion*. Strangely enough, there can be a subtle and complex kind of order to chaos. Scientists try to describe this order with models called *strange attractors*.

Science Activity 4.4 Drag Force

Objective: To be able to understand what factors create a drag force

Materials:
- A graphic diagram showing different forces in operation including the force that has an anti-lift and drag component.
- A permanent magnet, or an electromagnet, or a superconducting magnet
- A loop of wire

Procedures:
1. Explain Lenz's law that states that when a conductor experiences a changing magnetic field in respect to time, "eddy currents" will be induced (set-up) in the conductor.
2. These currents create a magnetic field which tends to cancel the change in magnetic field experienced by the conductor. The opposite magnetic fields create repulsion.
3. As a permanent magnet or a superconducting magnet moves over a passive loop of wire. The magnet is repelled up and back. The forces are called lift and drag respectively.
4. The forces are different for the high speed and low speed cases. In the low speed case, the coil responds to the reduced external magnetic field due to the fact that the magnet is now mov ing away from the coil.
5. The coil responds with a current in the same direction as that in the current loop, and hence an attractive force results. This force has an anti-lift and a drag component.
6. In the high speed case, the coil doesn't have time to respond to the reduced external magnetic field; it takes time for the current to change directions. The current direction doesn't change and a repulsive force results. Here we have lift and anti-drag components.
7. The anti-drag force almost cancels the drag force. Hence at high speeds, the magnetic drag force is substantially decreased.

Assessment and Review:
1. Define drag force and give an example.
2. What are "eddy currents."
3. Explain Lenz's law.

Science Activity 4.5 The Magic Dancer

Objective: To demonstrate repulsive forces of magnets

Materials:
• Two small disc magnets
• A wooden stand, tape

Procedure:
1. Construct a stand of wire in a wooden base and cut out a cardboard dancer figure.
2. Hang the dancer on the stand with a thread
3. Tape a disc magnet directly under the figure and conceal another disc magnet at the end of the leg of the figure.
4. Move the dancer a little and observe.

Assessment and Review:
1. Why does the figure keep on moving?
2. How do the magnet poles have to be arranged?
3. Why does the base have to be made out of wood?

Extension:

The two concealed disc magnets are placed facing each other with like poles, so that they repel each other. This way the figure keeps on bouncing away from the point vertically under it, causing it to move and twirl for quite an extended time. If the base of the stand were made out of iron or any other magnetic material, the magnet concealed in the base would lose much of its magnetism and the upper magnet would be attracted to any part of the base and would stop moving.

Chapter 5

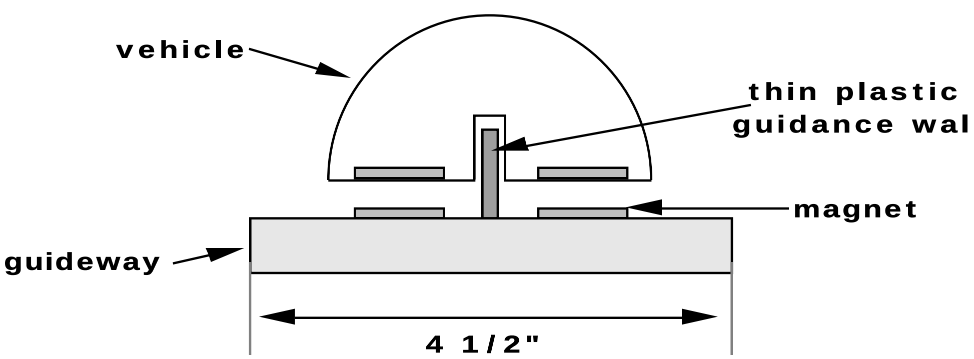
MagLev Operations

Make your own Maglev!

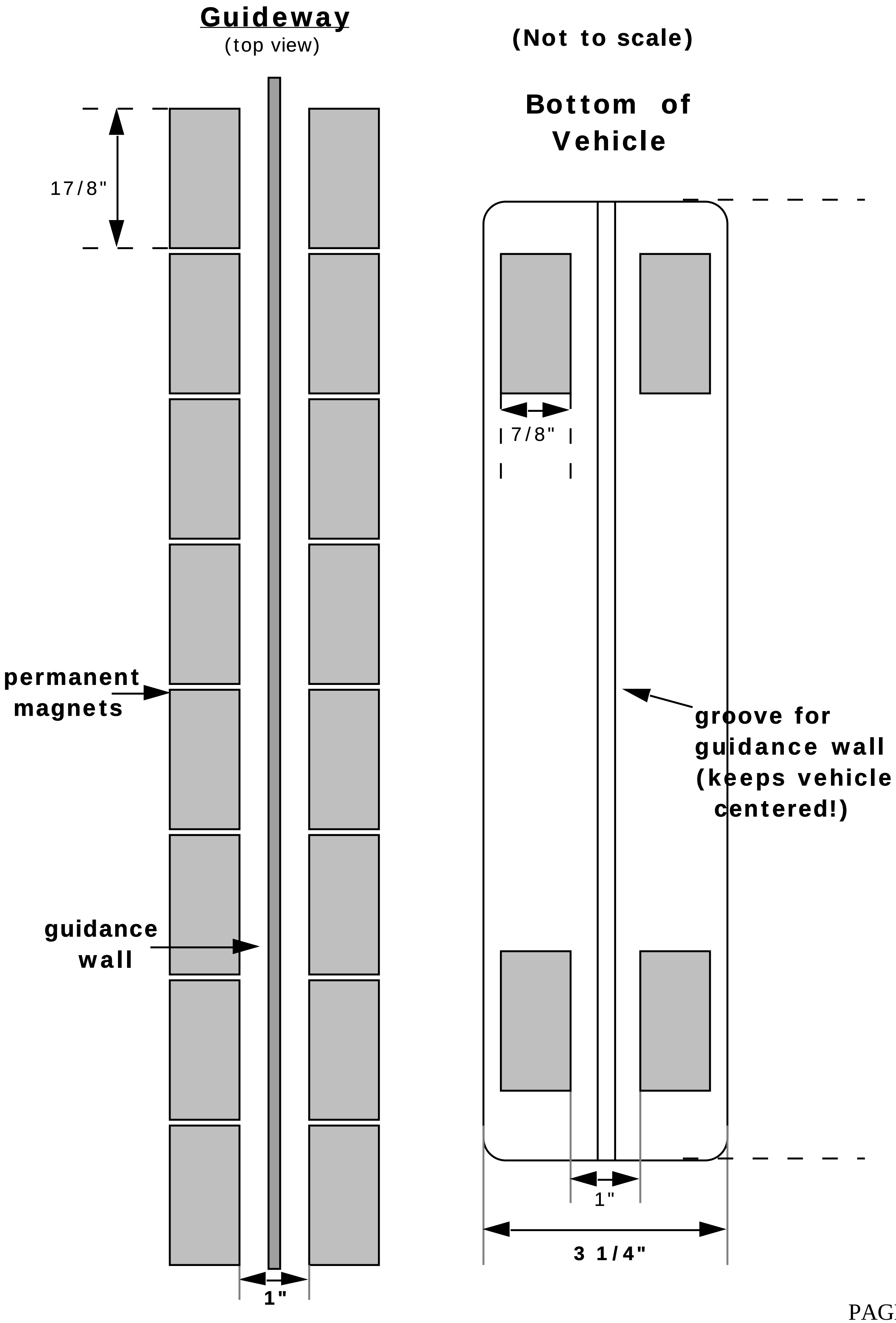
How do Maglev systems work? By using a simplified system, an interesting although expensive option can be used as a class project to demonstrate how a maglev system works.

Below is an illustration of a demonstration Maglev that was built at Argonne National Laboratory. It levitates because of the repulsive force between like magnetic poles of permanent magnets. The vehicle is propelled by hand!

Rear View



dimension \ object	Vehicle	Magnets	Guideway
length	2 feet	1 and 7/8 inches	3 feet
width	3 and 1/4 inches	7/8 inches	4 and 1/2 inches


Guideway
(top view)
(Not to scale)
Bottom of Vehicle
17/8"
7/8"
permanent magnets
groove for guidance wall (keeps vehicle centered!)
guidance wall
1"
1"
3 1/4"

The most difficult part of building a model like this is that you have to keep your vehicle from falling off the guideway. Instead of a thin rod keeping the magnets stable, the thin plastic wall in our model is what does the job: it fits loosely into a groove on the bottom of the vehicle and keeps it from falling off one side or the other of the guideway.

It takes some time to figure out the best positions of all the magnets, but that's what experimentation is about.

This model uses 4 magnets on the vehicle and 30 on the guideway. Each magnet is rectangular: 1 and 7/8 inches by 7/8 inches and 3/8 inches thick (17/8" x 7/8" x 3/8"). The lengths of the vehicle and of the guideway are shown in the picture. Making both the vehicle and the track shorter would reduce the number of magnets that you will need. The magnets are held in place using double-sided sticky tape; they are taped to the vehicle and to the guideway. Modeling clay does a good job too and makes adjustments easier.

Magnets may be purchased from Edmund Scientific or Radio Shack. Radio Shack has the better prices.

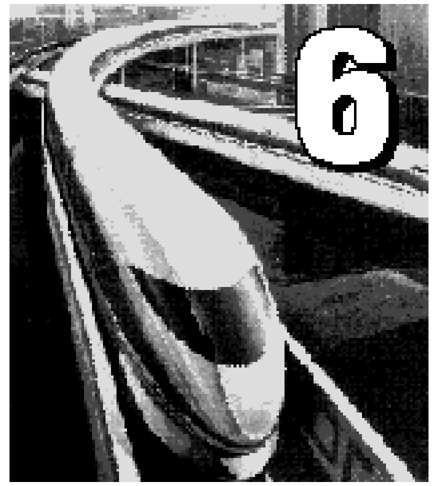
Materials Needed	**Where to get them**
12 to 36 rectangular permanent magnets (ferrite based) 17/8" x 7/8"	Edmund Scientific Company Item # D41,799 = 12 for $18.75 (Item # D41, 798 = 2 for $5.25)
guideway: (could be wooden)	hardware/home/school
thin wall for center of guideway (could be cardboard)	home
tape: 2) double-sided tape	hardware store
modeling clay;	hardware store?/hobby store
vehicle: **Keep it light-weight!**	

You can get as fancy as you want with the vehicle. It is suggested to keep it simple for now and get the thing to work before spending a lot of time making the vehicle very fancy.

Radio Shacks are located throughout the area. Edmund Scientific can be contacted at:
Edmund Scientific Company
Order by phone: (609)-573-6250
101 E. Gloucester Pike
Barrington, New Jersey 08007-1380

Chapter 6

High Speed Trains



What is a high speed train? How is it different from a maglev vehicle? High speed trains roll on wheels while maglev vehicles surf on magnetic waves. Steel wheels rolling on steel rails support the weight of a train and propel it forward. The wheels are also pushed inward by the rails to prevent the train from derailing and to guide it around curves.

Rotary electric motors cause the wheels to turn. The magnet rotates because it is pushed and pulled forward by the changing magnetic field of the motor's electromagnets. The current in the electromagnets change direction, and the polarity of the electromagnet is reversed. How quickly the polarity changes determines how fast the motor will turn. The magnet is attached to the train wheel through an axle.

Let's think about friction for a moment. Does friction aid or hinder the rolling of a train? Think about the difference between riding a "Big Wheel" and a bicycle. You are more likely to spin your wheels on a "Big Wheel" than on a bicycle because there is more friction between a rubber wheel and pavement than between a hard plastic wheel and pavement.

This is the same reason that the wheels of a car spin on ice — not enough friction. The tire of a car pushes backward against the road and, through friction, the road pushes back on the wheel. You have probably heard that "for every action there is an equal and opposite reaction." This is Newton's Third Law of Mechanics, and it can be used to describe wheeled transportation.

Newton’s Third Law

For every action there is an equal and opposite reaction.

That is, the wheels of a train push back against the rails, and the rails respond with an equal and opposite force pushing the train forward.

Thus we see that friction is an aid to rolling, but friction can also hinder rolling when a train’s wheels slide against the rail. Imagine that there is a bump in the rail causing a wheel to *momentarily* leave the rail. When the wheel bounces back down on the rail, it may skid along for a moment. (It is not uncommon for the wheels to momentarily leave the rail. If the train hits a very large bump, it may derail.) Also, when the train is going through a curve, the side of the wheel may slide against the rail.

All of these forces on the rails may cause them to become misaligned. For safety reasons, therefore, the rails have to be checked regularly, and adjusted if necessary. So, the answer to our earlier question is that rolling friction aids the motion of a train, but sliding friction hinders the motion of a train. There is another place where sliding friction causes a drag force on a train, and it has to do with how the train receives its electrical power.

Electricity is passed to the train through a metal “pantograph” on top of the train which slides along overhead wires. Electric current flows from the wires, through the pantograph, to the rotary electric motors. Friction between the pantograph and the wires tends to slow down the train. This friction limits the maximum speed of the vehicle because parts become worn out and the mechanical contact between the pantograph and the wire can be difficult to maintain at high speeds.

Nevertheless, a French high speed train, the TGV (*Train á Grande Vitesse*), has rolled at 515 km/hr! Such high speeds are difficult to maintain, so the normal operating speed of the

TGV is 300 km/hr. As technology improves, however, the operating speed of high speed trains will increase.

Several high speed train systems run in foreign countries, and have an unblemished safety record. Among these systems are the TGV in France, as mentioned already, the ICE (Inter-City Express) in Germany, and the Shinkansen in Japan. High speed rail should be coming to the United States soon: the State of Texas plans to install 800 km of the TGV by 1998.

Maglev vehicles are supported, guided and propelled by magnetic fields, while steel wheels rolling on steel rails perform these functions for high speed trains. Maglev vehicles can climb steeper grades than can high speed trains because they are not limited by friction. Maglev gets its power without any mechanical contact, but electricity is delivered to a high speed train via a sliding contact. A high speed train has a locomotive which holds the power conditioning equipment and the rotary electric motors. In a maglev system, the linear electric motor is located in the guideway and not on-board the vehicle.

Why do we say "maglev vehicles" instead of "maglev trains?" Well, a train means that several cars are connected together. Since a train's locomotive is usually fairly heavy, it makes sense to pull as many cars as possible in order to use energy efficiently. Because maglev's linear motor is on the guideway and not on the vehicle it could operate with one or more cars with similar energy efficiency. A maglev with only one car would be more like an airplane without wings in terms of the number of passengers it would carry, and the shape of the vehicle.

Maglev makes less noise than high speed trains at the same speed because there is no mechanical contact. The amount of electrical energy used by high speed trains is similar to that used by maglev (at comparable speeds), so the environmental benefits are similar. Both types of high speed ground transportation are much more energy efficient than airplanes.

They can travel as fast as 500 km/hr using 1/3 the energy of airplanes. Any time energy is conserved, the environment is helped by consuming fewer resources and creating less pollution. The speed of passenger airplanes is about 500 km/hr so how can high speed trains and maglev save time compared to an airplane? Because airports are so busy, airplane passengers spend much of their time just waiting around. In addition, high speed ground transportation could connect city centers, thus saving passengers the trip out to the airport. Saving time means saving money. Getting there quicker saves money for both passengers and airports. In fact, high speed trains or maglev could be used to connect even airports to each other.

Chapter 7

Career Opportunities

With the invention of Maglev, existing careers in engineering, construction and manufacturing will take on new dimensions.

A test track will need to be developed to test the principles of Maglev. The initial effort will require 30-100 personnel from a variety of state, industrial, and academic institutions to design, construct, and analyze the test track. These personnel will include the following professionals: urban, rural, and regional planners, architects, economists, financial analysts, transportation system designers, physicists, environmental scientists, and a variety of engineers. There will also be a continuing process of testing alternative hardware and analyzing commercial systems. For this, 10-20 professionals will be required to stay on staff for automation purposes.

Urban and rural planners are needed to select the appropriate site. They will work with Congress and the Federal Administration to determine a proper location. If the site chosen is along an interstate highway, the acquiring of more land is not necessary. However, if the new land will need to be acquired for those areas not aligned with the interstate road system, lawyers will be needed to resolve the imminent domain issues.

The developmental phase of the Maglev is a basic construction project. It is a cross between an airline and a railroad. Numerous types of engineers will be needed, including civil, aeronautical, mechanical, and electrical. Civil engineers will be used for road construction, while aeronautical engineers will design systems in which air resistance and the motion of the train will contribute to maximum speed. Mechanical engineers will be responsible for cryogenics and cooling equipment, making sure the magnets work properly. The physicist and the electrical engineers will develop the blueprints that the electricians will follow to install, operate, and repair the Maglev.

Skilled, semi-skilled, and unskilled labor will be used in constructing the Maglev. The skills of these laborers will be especially useful when the interstate highway system cannot be used as a right-of-way. Existing factories and steel mills will provide the basic construction necessary to build the Maglev. Additional factory workers may be required to meet the initial needs for Maglev materials.

Once in operation, the Maglev system will be connected with the airline and train services. Reservationists, ticket agents, shuttle buses, taxi, and car rental agencies will interface with existing services. The need for transportation as a time saving mechanism is an ever present need and problem. Maglev presents a possible solution to this problem. As a nation, we should use our talents and resources to attain what appears to some an impossible dream - a reality!

Chapter 8

Maglev and Society

EMF'S: Possible Health Hazards!

Although maglev is deemed a safer mode of transportation, it may pose a danger of its own. Passengers would be exposed to electromagnetic fields, the same kind that are produced by power wires and many household appliances. These standards for exposure to electromagnetic fields, or EMF's as they are called, have not been established yet and there is much controversy over whether they pose any threat.

Some research has linked EMF's to increased rates of brain cancer and leukemia, especially among electrical workers. Studies point to research which reveal that EMF's are responsible for altering cellular or nervous system receptors. Other studies show absolutely no relationship. More time is needed to determine long-term effects. Although there is currently not valid evidence to determine if EMF's pose a definite health hazard to people, maglev technicians are taking measures to ensure that passengers are shielded from potential danger from EMF's . Careful placement of magnets on iron shields protect the passengers' compartment and greatly reduces the magnetic fields generated by the levitation and propulsion of magnets.

Although measures to reduce EMF's would increase the cost of building the maglev system, the expense of operating this new transportation over a long period of time would even out the cost for High Speed Trains. Over the life span of the guideway it would be less expensive to maintain because there is no contact between the vehicle and the guideway so wear and tear and misalignment is minimized.

Right of way costs and land development can be reduced by using existing airports, shopping centers, parking lots, highway railroad, and utility rights-of-way. Fuel expenses would also be lower since, as we have said, maglev trains are not dependent on petroleum, but rather on electricity.

MAGLEV HEALTH & SAFETY

Science Activity 8.1 Magnetic Shielding

Objective: To learn how to shield certain sensitive instruments from magnetic lines of force

Material:

• Two magnets

• Compass

• Some high permeability material, such as, glass or wood, which will fit around the compass

Teacher Preparation:

It has long been determined that magnetic lines of force will penetrate any nonmagnetic material. Nonmagnetic materials such as glass, copper, or wool allow magnetic lines of force to pass through them very freely, whereas magnetic substances, such as iron and steel, are frequently used as barriers to prevent the penetration of magnetic lines of force. It is oftentimes necessary or desirable to shield certain sensitive instruments and keep magnetic lines away from them. When this is necessary, we can make use of the fact that some magnetic materials concentrate magnetic lines of force.

In order to shield something, we put a good conductor of magnetism all around it so that the lines of force will take the easy path through the shield rather than the more difficult one through the air, which would allow them to go through the material we wish to shield. The lines of force will always follow the easiest magnetic path.

Procedures:

1. Place a compass inside a “tin” can. The compass should rest about the center of the can on a little support which can be made out of any nonmagnetic material. Now place the two

magnets on opposite sides of the can with unlike poles facing so that under normal circumstances there would be magnetic lines of force going straight through the can and thus influencing the compass. You'll perhaps notice a slight effect on the compass when the magnets are brought into position. This is due to the fact that the permeability of an ordinary tin can isn't quite good enough for this experiment.

2. To make the experiment more successful, place this tin can into another of larger diameter and check again. If the shielding is still not as effective as you would like it to be, place the two cans into a still larger one. You will find that the magnetic field will be progressively lessened as we interpose more and more permeability shield.
3. Here is another way of showing the effect of a high permeability material. Place the compass about 10 inches away from the magnet, and note the effect the magnet has on the compass needle. Then put some materials between the magnet and the compass such as, copper, glass, wood, or any other nonmagnetic material, you will see that there will be no noticeable effect. Now try a magnetic material such as the tin can we use earlier. If you allow the magnet to touch the can, you will see that it will effectively "short-circuit" the magnetic field, because of the easier magnetic path it offers, and thus prevent the lines of force from going through and reaching out to the compass.
4. Sensitive electrical coils in measuring instruments or in radio circuits are often placed inside iron or steel containers so as to by-pass or effectively short-circuit any interfering external magnetic field.

Assessment and Review:

1. Students are to develop a data table based on the procedures given above.
2. Students will then record compass deflection for different materials used to test for shielding.
3. Based on the data table that students develop, they will determine which materials have high permeability in relations to magnetic fields.

Science Activity 8.2 How Much Force Do You Need?

Objective: To learn how a nonmagnetic substance between two magnetic objects can affect the magnetic attraction between them.

Materials:

• Ring stand

• Scissors

• 15-cm string

• Two large paper clips

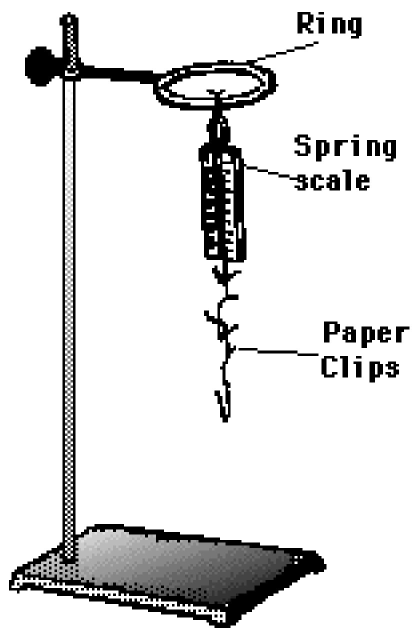
• Two index cards, 3 x 5

• A pencil

• Spring scale

• Magnet

• Metric ruler.



Procedures:

1. Divide each index card into 15 squares, each 2.5 x 2.5 cm. Cut the squares out with scissors.
2. Set up the ring stand and ring by tying the top of the spring scale to the ring as shown in the diagram above.

3. Open the ends of each of the two paper clips. Then twist the open end of the two clips tightly together. Take one free loop of the paper clips hang on the bottom hook of the spring scale. Do this by twisting the loop to fasten it to the scale.
4. Touch the magnet to the free end of the paper clip. Slowly pull down the paper clip until it gently pulls or breaks away from the magnet.Watch the scale to see how much force, in newtons, you must use to pull the clip away. Record the reading on the scale.
5. Do step #4 two more times. Record the number of newtons for each trial. Find the average of the three trials and record it.
6. Place one paper square as a spacer between the paper clip and the magnet. Slowly pull down on the magnet until the magnet breaks away. Observe the force required and record the re sults. Do this step two more times. Find the average force for the three trials.
7. Stack two paper spacers, one on top of the other. Place them between clip and the magnet. Repeat the procedure in step # 6. Do the same with 3, 4, 5, and 10 spacers. Record each time the results and average the three trials.
8. Plot the results on a graph, placing the number of spacers on the horizontal axis of the graph. Then plot the force in newtons on the vertical axis of the graph. Finally, draw the curve.

Assessment and Review:

1. What is the relationship between magnetic force and thickness of barrier between the magnet and attracted object?
2. What can happen to the average force needed to separate the magnet and paper clip as the number of spacers increase? Decrease?
3. What implications does this activity have on other experiments on magnetism? Review the steps that were used in this activity.

4.Why were spacers used?

5. Why was it important to record the results?

6.Why is it necessary to plot a graph?

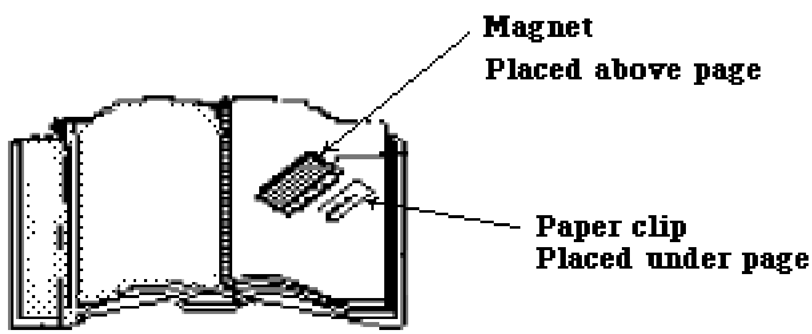
7. What conclusions can be reached after plotting the graph?

Science Activity 8.3 What Is The Extent Of A Magnetic Field?

Objective: To learn how the distance between a magnet and an iron object affects the magnetic field.

Materials:

- Paper clip
- A thick phone book
- A bar magnet



Procedures:

1. Support the back cover of a thick phone book on a high block.
   Place a paper clip under the back cover. Put a magnet on the opposite side of the back cover and check the attraction between the clip and the magnet. See the diagram above.
2. Put a few more pages of the phone book between the paper clip and the magnet. If the paper clip is still attracted, then add a few more pages to increase the distance between the magnet and the paper clip.
3. Record the number of pages that are added each time and note if there is an attraction.
   (A chart can be used to record the results!)

4. Continue step 3 until the distance between the two is go great that the paper clip is no longer held to the bottom of the book.
5. Measure and record the height of the stack of pages and cover.

Assessment and Review:

Review the study of magnetic field in terms of lines of force and the range of magnetic attraction.

1. Is the paper clip attracted by the magnet?
2. How does the distance between an iron object and a magnet affect the magnetic attrac tion?

Science Activity 8.4 Materials That Block Magnetism

Objectives: To find out which materials block magnetism

Materials:

• Horseshoe magnet for each pair of students

• Iron filings

• Piece of cloth

• Piece of paper

• Thin sheet of plywood

• Sheet of aluminum foil

• Base of iron ring stand

• Stainless steel cookie sheet

• Glass plate

Teacher Preparation

Familiarize students with the idea that all magnetic materials are also composed of magnetic domains. However, as students will find out in this activity, some materials are not attracted to magnets? Why aren't they? Are these materials composed of magnetic domains? Do such materials block magnetism?

In preparing this activity, the materials listed above are just a suggestion, any objects that are available may be used instead. Students may find it easier to work in pairs for this activity. One student can hold the material while the other handles the magnet.

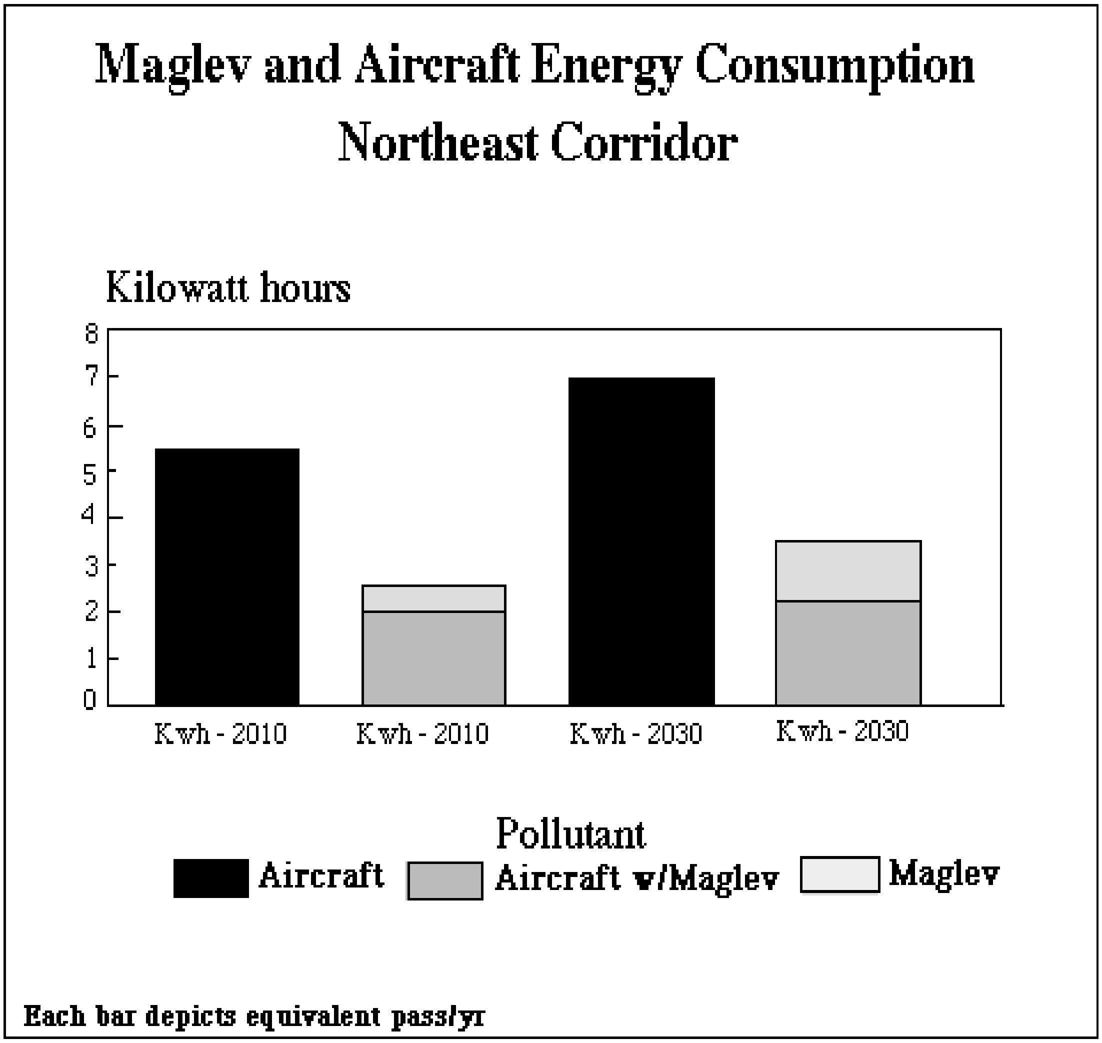
Procedures:

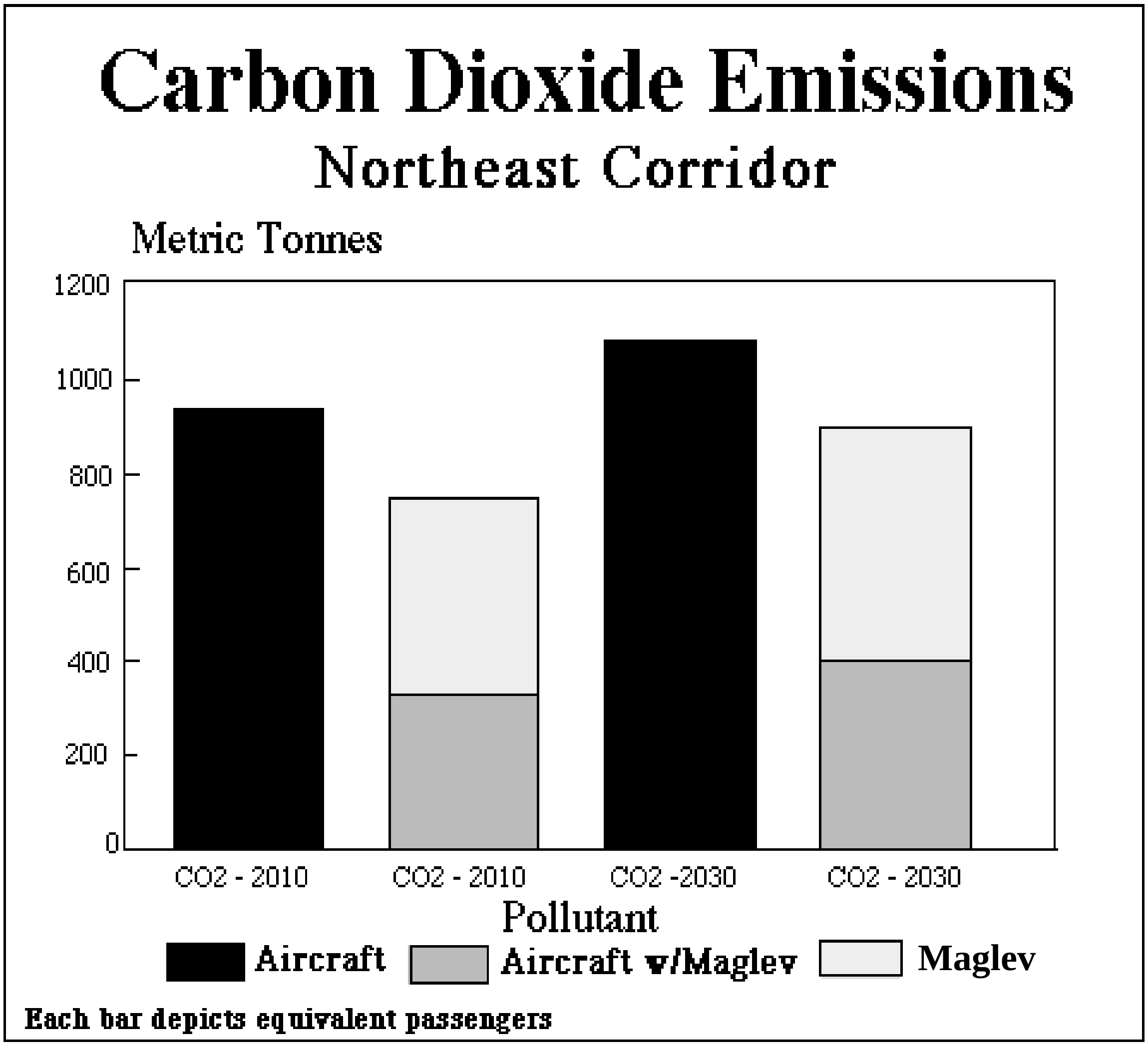
1. Place iron filings on a sheet of paper. Move the magnet back and forth under the paper. Observe the filings.
2. Repeat step 1, substitute each of the other material, such as, cloth, glass, wood, etc. for the paper.
3. Summarize the results in the Data Table below.

Data Table

Material	Does Not Block	Blocks Magnetism
Cloth		
Paper		
Foil		
Glass		
Iron ring stand		
Stainless steel sheet		
Wood		

Appendix A


Maglev and Aircraft Energy Consumption
Northeast Corridor
Kilowatt hours
8
7
6
5
4
3
2
1
0
Kwh - 2010
Kwh - 2010
Kwh - 2030
Kwh - 2030
Pollutant
Aircraft
Aircraft w/Maglev
Maglev
Each bar depicts equivalent pass/yr



Carbon Dioxide Emissions
Northeast Corridor
Metric Tonnes
1200
1000
800
600
400
200
0
CO2 - 2010
CO2 - 2010
CO2 -2030
CO2 - 2030
Pollutant
Aircraft
Aircraft w/Maglev
Maglev
Each bar depicts equivalent passengers

Appendix B

Maglev Resources:

Amtrak, Washington, D.C.

Argonne National Laboratory, Argonne, Illinois

California-Nevada Super Speed Train Commission, Las Vegas.

Caltrans, Los Angeles-Bay Area High Speed Rail Study Group, Sacramento.

Carnegie Mellon High Speed Ground Transportation Center, Pittsburgh.

Florida High Speed Rail Transportation Commission, Tallahassee.

High Speed Rail Association, Pittsburgh.

Illinois Department of Transportation, Springfield.

Michigan Department of Transportation, Lansing.

Ohio High Speed Rail Authority, Columbus.

Ontario-Quebec High Speed rail Task Force, Toronto.

Texas High Speed Rail Authority, Austin.

United States Army Corps of Engineers, Washington, D.C.

United States Senate Maglev Technology Advisory Committee,
Washington, D.C.

Washington Department of Transportation, Olympia.

Wisconsin Department of Transportation, Madison.

Appendix C

Periodical Literature on MagLev Vehicles:

Airplanes, high-speed trains: the 21st - century connection. Author: Bruce D. Nordwall. *Avia tion Week & Space Technology*, Volume 136:54-56, January 13, 1992.

An article on high speed rail that will become the transportation mode of choice for heavily traveled short-to-medium routes. A high-speed steel rail system in Texas and a magnetic levitation system in Orlando, FL, are described.

Assessing the economic feasibility of maglev. Author: Bruce Rose. *Mass Transit*, Volume 19:28-30, September-October, 1992.

The article describes how increasing congestion in urban areas across the US is stimulating interest in the application of high-speed rail and magnetic levitation technologies in mass transit systems. Some issues have to be answered first, however, and among theseare choosing the proper technology, finding the appropriate corridors, environmental impacts and economic feasibility.

Debating the future of Maglev. Author: Jon Van. *Journal of Commerce and Commercial*, Volume 393:6A, August 7, 1992.

Grumman rolls out new Maglev design. Author: Paul Demery. *Business News*, Volume 51:1-2, May 11, 1992.

Living-room levitation: scale-model maglev trains. Gregory T. Pope. *Discover*, Volume14:24-25, June 1993.

The article describes how a retired engineer, Robert J. Lawrence plans to market toy magnetic-levitation (maglev) trains, scale models of designs solicited by the US Transportation Department.

High-speed rail development forecast to remain in low gear. Author: William DiBenedtto. *Journal of Commerce and Commercial,* Volume 395:3B, March 22, 1993.

High speed trains now and later: we have options. Author: Robert G. Lewis. *Railway Age*, Volume 194:96-97, May 1993.

Mag-lev train doesn't have Clinton aboard. Author: Thomas J. Smith. *Baltimore Business Journal*, Volume 10:3-4, May 7, 1993.

Maglev: grant extension or high-speed rail will die. Author: Melissa Stoker. *Orlando Business Journal*, Volume 9:5, March 19, 1993.

New suspension may smooth maglev ride. Author: Elizabeth Pennisi. *Science News*, Volume 41:55-56, January 25, 1992.

New York looks at maglev trains. Author: Lawrence Lennon. *American City & County*, Volume 107:65-68, October 1992.

New Your is considering the use of maglev trains to aid its transportation system.

Riding on air: high-speed trains. Author: Gary Stix. *Scientific American*, Volume 266:104-105, February 1992.

Congress approved a $151 billion surface transportation bill that provides funding for magnetically levitated vehicles across the country.

US urged to get magnetically levitated train on track. Author: Peggy Abrahamson. *American Metal Market*, Volume 100:4-6, June 5, 1992.

Will trains ever fly? Benefits and obstacles relating to rail transport. Author: Steve Salerno. *The American Legion.* Volume 133:26-30, November 1992.

Appendix D

MagLev Reference Books:

Allen, Geoffrey Freeman. **Railways of the Twentieth Century**. New York: W.W. Norton, 1983.

Cohen, Linda R. and Roger G. Noll. **The Technology Pork Barrel**. Washington, D.C.: Brookings Institute, September, 1990.

Cupper, Dan. **The Pennsylvania Turnpike—A History**. Lebanon, Pa.: Applied Arts Publishers, 1990.

Hughes, Murray. **Rail 300: The World High Speed Train Race**. North Pomfret, Vt.: David & Charles Inc., 1988.

Itzkoff, Donald M. **Off The Track: The Decline of the Intercity Passenger Train in the United States**. Westport, Conn.: Greenwood Press, 1985.

Lyon, Peter. **To Hell in a Day Coach**. New York: J.B. Lippincott, 1966.

Pell, Claiborne. **Megalopolis Unbound: The Supercity and the Transportation of Tomorrow**. New York: Frederick A. Praeger, Inc., 1966.

Renner, Michael. **Rethinking the Role of the Automobile.** Washington, D.C.: Worldwatch, 1989.

Runte, Alfred. **Trains of Discovery**. Niwot, Colo.: Roberts Rinehart, Inc., 1990.

Southerland, Jr., Thomas C. and William McCleery. **The Way to Go: The Coming Revival of United States Rail Passenger Service.** New York: Simon and Schuster, 1973.

Vranich, Joseph. **Supertrains.** St. Martin's Press: New York, 1991.

Appendix E

Glossary

alnico - One of a series of ferrous alloys containing aluminum, nickel, and cobolt, valued because of their highly retentive magnetic properties.

ampere - The unit of electrical current in the meter-kilogram-second system of units. Abbreviated a; A; amp.

attractive force - A force that attracts or pulls other objects towards another object.

circular electric motor - An electric motor in which the center magnet moves around in a circle.

compass - An instrument with a magnetic needle that is able to pivot and will always point towards the north and south magnetic poles.

conductor - A material that will allow electricity to pass through.

diamagnetic - Having a magnetic permeability less than 1; materials with this property are repelled by a magnet and ten to position themselves at right angles to magnetic lines of force.

drag force - Air resistance created as a vehicle is moving through air.
eddy current - A circular movement of electrons in a metal caused by a magnet moving past the metal.

electric current - Electrons moving through a conductor (wire).

electric field - The field created around a conductor as electricity passes through.

electromagnet - A magnet created by electricity passing through a coil of wire.

electromagnetic induction - The production of an electromotive force either by motion of a conductor through a magnetic field or by a change in the magnetic flux that threads a conductor.

equipotential surface - A surface which is always normal to the lines of force of a field and on which the potential is everywhere the same.

flux - All the magnetic lines of force added together.

galvanometer - An instrument used to detect the strength of an electric current.

galvanoscope - An instrument that detects the presence of an electric current.

guideway - The "track" on which a magnetically levitated vehicle travels.

insulation - A substance that will not allow electric current to pass through.

iron core - Iron inside a wire coil that strenghens the magnetic force of the electromagnet.

Lenz's law - The law that whenever there is an induced electromotive force (emf) in a conductor, it is always in such a direction that the current it would produce would oppose the change which causes the induced emf.

levitation - The raising of an object into air without supporting the object physically.

linear electric motor - A motor in which the electromagnets cause the magnet to move in a straight line.

loadstone - Nautral occurring magnetic iron oxide, or magnetite, possessing polarity, and attract ing iron objects to itself.

Lorentz force - The force on a charged particle moving in electric and magnetic fields. It is equal to the particle's charge times the sum of the electric field and the cross product of the particle's velocity with the magnetic flux density.

maglev - Magnetically levitated vehicle.

magnet - A piece of iron, steel or magnetite that will attract iron or steel.

magnetic field - A region in the space around a magnet where the magnetic force can be felt.

magnetic induction - A vector quantity that is used as a quantitative measure of magnetic field.

magnetic lines of force - Imaginary lines that show the direction and strength of the magnetic field around a magnet.

magnetic material - A material exhibiting ferromagnetism such as, iron, nicker, and cobolt.

magnetic pole - One of two ends of a magnet where the magnetic lines of force are concentrated and are the strongest.

magnetism - The property of matter which allows an object to attract iron, steel or magnetite.

magnetite - A mineral rich in iron that has magnetic properties.

magnetize - The process of giving magnetic propeties to a magnetic material.

north magnetic pole - The end of a magnet that points to the north.

permanant magnet - A magnet that will keep its magnetism for a long time.

permeability - A factor, characteristic of a material that is proportional to the magnetic induction produced in a materaildivided by the magnetic field strength.

repulsive force - A force that pushes two or more objects away from each other.

residual magnetism - The magnetism that remains after an object has been magnetized..

retentivity - Indicates how long a substance will retain its magnetism after the magnetizing force is removed.

south magnetic pole - The end of a magnet that points to the south.

superconducting magnet - An electromagnet whose coils are made of a type II superconductor with a high transition temperature and extremely high critical field, such as niobium tin, Nb_3Sn.

temporary magnet - Magnets that lose their magnetism quickly.

Cover designed by Nick Repkin, Argonne

Argonne National Laboratory is operated by The University of Chicago for U.S. DEPARTMENT OF ENERGY